



To Retain or Remove the Bone Flap During Evacuation of Acute Subdural Hematoma: Factors Associated with Perioperative Brain Edema

Ha Son Nguyen, Karl Janich, Ashish Sharma, Mohit Patel, Wade Mueller

■ BACKGROUND: The fate of the bone flap is a significant decision during surgical treatment of acute subdural hematoma (SDH). A general guideline revolves around the surgeon's concern for brain edema. Limited studies, however, have focused on the factors that contribute to perioperative brain edema.

■ METHODS: From 2012 to 2015, 38 patients who underwent decompressive craniectomy for acute SDH were reviewed. Clinical data were extracted (age, sex, initial Glasgow Coma Scale (GCS) score, sodium level, hematocrit, and intraoperative blood loss). From the preoperative scan, SDH volume, midline shift (MLS), and volume within the skull (to estimate baseline brain volume) were measured. From the postoperative scan, brain volume (including any herniating regions) was measured. $\Delta\%$ was defined as the percentage change in postoperative brain volume compared with preoperative volume. Evident contralateral injury, contusions, and intraventricular hemorrhage (IVH) were noted.

■ RESULTS: Fifteen patients demonstrated negative $\Delta\%$. Univariate analysis found significant correlations between $\Delta\%$ and preoperative MLS, initial GCS, presence of IVH, and presence of contralateral injury ($P < 0.05$). A multiple regression for $\Delta\%$ elicited a significant model ($F [3, 34] = 17.387, P < 0.01$) with $R^2 0.605$, where $\Delta\% = 16.197 - 1.246 * GCS - 0.986 * MLS + 3.292 * IVH$ (with 0 = no IVH, 1 = presence of IVH).

■ CONCLUSIONS: A high proportion of patients can exhibit negative $\Delta\%$, or relative brain compression after decompression of SDH. For these patients, replacement of the bone flap may be reasonable to avoid obligatory interval cranioplasty. Preoperative MLS, initial GCS, and presence of IVH can help predict whether overall brain volume will swell or compress within the normal confines of the skull. This can guide the decision to retain or remove the bone flap.

INTRODUCTION

The fate of the bone flap is a significant decision during surgical treatment of traumatic acute subdural hematoma (SDH). A general guideline revolves around the surgeon's concern for brain edema perioperatively. Retention of the bone flap confers a greater potential for intracranial hypertension but negates the risks associated with obligatory interval cranioplasty. Not uncommonly, a postoperative computed tomography (CT) of the head may demonstrate a relatively sunken cranial defect with persistent midline shift after decompressive craniectomy (DC). Previous studies have noted wide variation with this clinical decision among surgeons around the world.^{1,2} Consequently, predictive preoperative factors to assess brain edema can help guide this clinical decision. As such, this study explored potential relationships between clinical factors and the extent of brain edema via analysis of perioperative imaging.

Key words

- Acute subdural hematoma
- Brain edema
- Trauma

Abbreviations and Acronyms

- $\Delta\%$: Percentage change in postoperative brain volume compared with preoperative volume
- CR: Craniotomy
- CT: Computed tomography
- DC: Decompressive craniectomy
- GCS: Glasgow Coma Scale
- IVH: Intraventricular hemorrhage
- MLS: Midline shift

SDH: Subdural hematoma

TBI: Traumatic brain injury

Department of Neurosurgery, Medical College of Wisconsin, Milwaukee, Wisconsin, USA

To whom correspondence should be addressed: Ha Son Nguyen, M.D.

[E-mail: hsnguyen@mcw.edu]

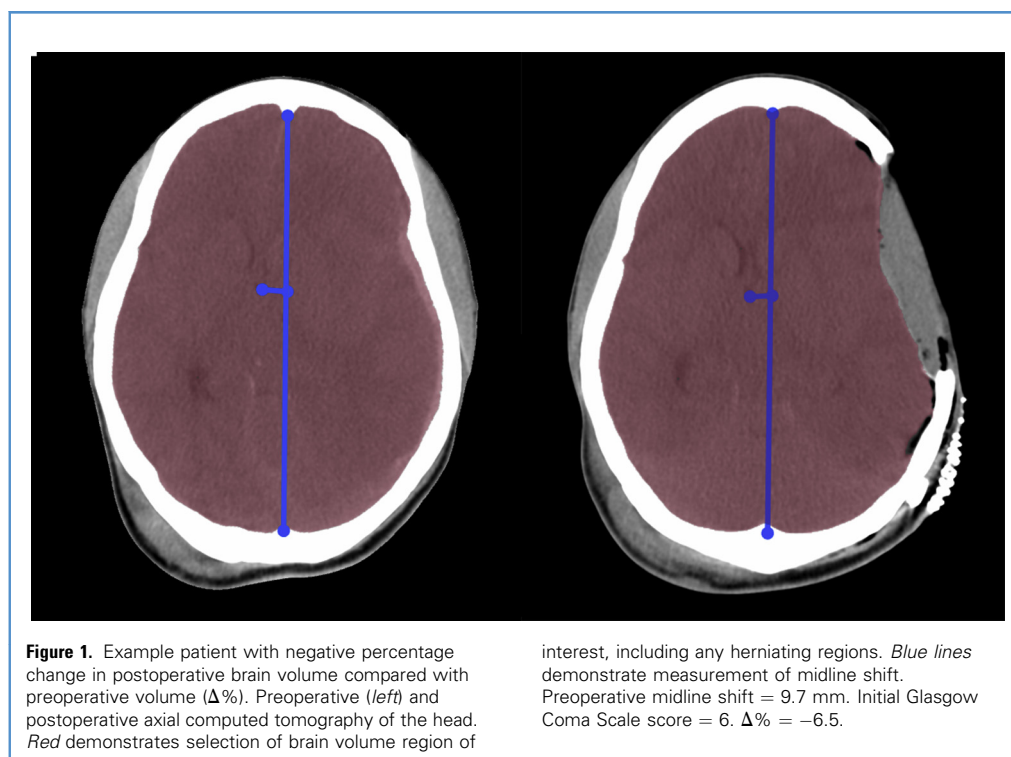
Citation: *World Neurosurg.* (2016) 95:85-90.

<http://dx.doi.org/10.1016/j.wneu.2016.07.067>

Journal homepage: www.WORLDNEUROSURGERY.org

Available online: www.sciencedirect.com

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We proposed that assessment of brain volume via CT imaging in patients without bone flaps is a reasonable model to study brain edema.

METHODS

The approval of the institutional board review at our hospital was obtained before the study. From 2012 to 2015, 38 patients who underwent DC for traumatic acute SDH were reviewed. Clinical data were extracted (age, sex, initial Glasgow Coma Scale [GCS], sodium level, hematocrit, and intraoperative blood loss). CT imaging was loaded into OsiriX MD (Pixmeo, Bernex, Switzerland). From the preoperative scan, SDH volume, midline shift (MLS), and volume within the skull (to estimate baseline brain volume) were measured. From the postoperative scan, brain volume (including any herniating regions) was measured (Figures 1 and 2). Volume was obtained by a semiautomated protocol to select the region of interest through axial CT images. The extent of brain edema was defined as $\Delta\%$, or the percentage change in postoperative brain volume compared with preoperative volume. Other parameters (presence of contralateral injury, contusions, or intraventricular hemorrhage [IVH]) were noted.

Statistical analysis was performed with IBM SPSS, Version 22 (IBM Corp., Armonk, New York, USA). Descriptive statistics (mean, standard deviation, and/or percentage) were computed for all variables. To identify the best predictors of $\Delta\%$, a linear multiple regression model was computed. First, univariate analysis was completed with $\Delta\%$ as the dependent variable and the other variables (age, sex, initial GCS, sodium level, hematocrit, intraoperative blood loss, presence of contralateral injury, presence of

contusions, presence of IVH, preoperative MLS, preoperative brain volume, and preoperative SDH volume) as independent variables. Then, a backward, multiple linear regression computation was carried out to evaluate $\Delta\%$. The independent variables that entered into the model were those with a $P < 0.10$ in the univariate analysis.

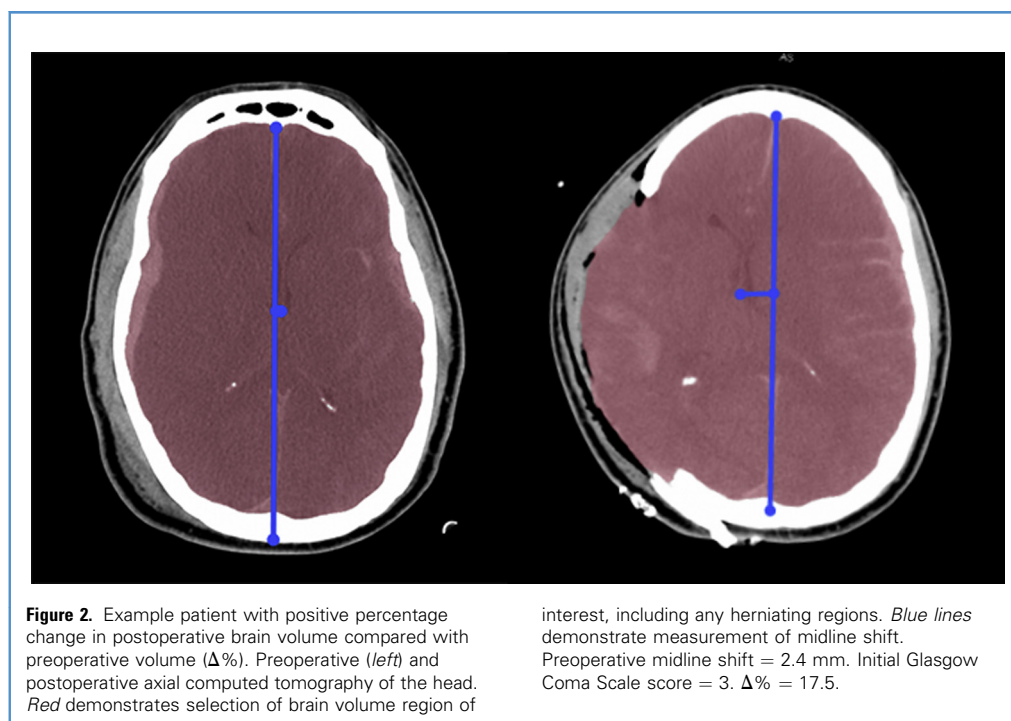
RESULTS

Table 1 summarizes the clinical factors. The mean age was 42.01 ± 13.65 years. There were 27 male and 11 female patients. Fifteen patients (39%) demonstrated negative $\Delta\%$. Univariate analysis found significant correlations between $\Delta\%$ and the following: preoperative MLS, initial GCS, presence of IVH, and presence of contralateral injury (all $P < 0.05$).

A backward, multiple linear regression for $\Delta\%$ that initially included all variables in which univariate analysis yielded $P < 0.1$ found a significant model that combined preoperative MLS, initial GCS, and IVH ($F [3, 34] = 17.387, P < 0.01$) with $R^2 0.605$, where $\Delta\% = 16.197 - 1.246 * \text{GCS} - 0.986 * \text{MLS} + 3.292 * \text{IVH}$ (with 0 = no IVH, 1 = presence of IVH) (Table 2). $\Delta\%$ decreased by 1.246 % for each point in GCS, decreased by 0.986% for each millimeter in preoperative MLS, and the presence of IVH imparted 3.292% more volume. Consequently, a negative $\Delta\%$ is possible with larger initial GCS, larger preoperative MLS, and absence of IVH.

DISCUSSION

Traumatic acute SDH is a frequently occurring neurosurgical pathology. Recent analyses report mortality rates of 15%–17%



for those treated operatively, where increased mortality was associated with coma, bleeding disorders, and severe systemic disease.³ Surgical options include craniotomy (CR) and DC, although the optimal approach remains controversial. The role of DC has been questioned, as bony decompression for acute SDH can result in exacerbation of edema^{4,5} and elevated intracranial pressures.⁶ Moreover, interval cranioplasty can pose substantial complications, including risks for infection, bone graft resorption, seizures, and extra-axial fluid accumulation.^{7,8} On the other hand, CR can require reoperation and possibly conversion to DC for up to 6%–16% of patients.^{9–11} As such, guidelines for these procedures can optimize surgical management of SDH.

Previous studies have attempted to evaluate the best surgical approach, but some may have suffered from selection bias, as patients who received DC exhibited worse baseline clinical characteristics. Wang et al.¹² found that DC generally was performed based on preoperative GCS score, pupillary changes, hematoma volume, injury/surgery time interval, MLS, cortical collapse, hematoma location, hematoma type, and ventricular deformation. Li et al.¹³ reviewed 91 patients (51 DC and 40 CR) and found the DC group had worse preoperative GCS, younger age, more extracranial injuries, and more severity on CT; interestingly, although the predicted outcome based on clinical factors were worse for DC group, the actual outcomes were comparable for the 2 groups, implying that DC may be more effective than CR. Tsermoulas et al.¹⁴ evaluated 99 patients (69 DC, 17 with “riding flap” CR, and 13 with “fixed retained flap” CR). The authors found that the DC group had poorer outcomes; however, the baseline characteristics between the

groups were significantly different; the patients with DC had significantly more severe mechanisms, lower GCS, more extracranial injuries, and greater Rotterdam CT scores.

A few studies attempted to account for the differences in clinical factors through subgroup analysis or better matched cohorts. Woertgen et al.,⁶ reviewing 180 patients (111 CR and 69 DC), found a greater rate of mortality in the DC group; this finding was attributed to more signs of herniation (pupillary changes) in the DC group. For patients with signs of herniation, outcomes were significantly worse regardless of the type of surgery; for patients without signs of herniation, there was no difference in outcomes between CR and DC. Kwon et al.¹⁵ evaluated 46 patients (20 CR and 26 DC) based on unfavorable features (age older than 70 years, anticoagulation or antiplatelet use, time to surgery >4 hours, GCS <8, nonreactive pupils, and major extracranial injury); for patients with few unfavorable features, good outcome was achieved in the majority of patients with CR; similar results were not obtained in DC group with few unfavorable features. Studies with better matched cohorts, including those by Chen et al.¹⁶ and Rush et al.,¹ found that DC exhibited a greater mortality compared to CR.

To complicate matters, wide variation exists with this clinical decision among surgeons.^{1,17} Within neurosurgical centers in the United Kingdom and Ireland, only 14% demonstrated intra-departmental agreement concerning the fraction of patients receiving DC for acute SDH.² Moreover, a greater proportion of neurosurgeons from other European nations (44%), compared with UK/Irish neurosurgeons (21%), use DC in more than half of acute SDH cases.¹⁷ In the United States, Rush et al.¹ noted

Table 1. Clinical Factors with Univariate Analysis for $\Delta\%$

Clinical Factor	Descriptive Statistic	Univariate Analysis: P Value
Total patients	38	
Age, years \pm SD	42.01 \pm 13.65	0.979
Sex		0.618
Male (%)	27 (71.1)	
Female (%)	11 (28.9)	
Laterality		0.723
Right (%)	25 (65.8%)	
Left (%)	13 (34.2%)	
Initial GCS score, \pm SD	5.32 \pm 2.78	0.004
Sodium level, mmol/L \pm SD	139.16 \pm 5.84	0.258
Hematocrit, % \pm SD	38.97 \pm 5.15	0.569
Intraoperative blood loss, mL \pm SD	647.37 \pm 421.86	0.258
Presence of contralateral injury (%)	15 (39.5)	0.011
Presence of contusions (%)	19 (50)	0.439
Presence of intraventricular hemorrhage (%)	5 (13.2)	0.036
Preoperative brain volume, cm ³ \pm SD	1486.57 \pm 172.45	0.325
Preoperative SDH volume, cm ³ \pm SD	63.54 \pm 31.35	0.289
Preoperative MLS, mm \pm SD	9.18 \pm 3.56	0.003
Area of bone flap, cm ² \pm SD	380.69 \pm 73.12	0.712
Postoperative brain volume, cm ³ \pm SD	1502.45 \pm 204.42	
$\Delta\%$		
Negative (%)	15 (39.5)	
Positive (%)	23 (60.5)	

The bold values indicate statistical significance with $P < 0.05$.
 $\Delta\%$, percentage change in postoperative brain volume compared with preoperative volume; GCS, Glasgow Coma Scale; SDH, subdural hematoma; MLS, midline shift.

that CR was performed 10 times more frequently than DC. Hopefully, the ongoing RESCUE-ASDH (Randomised Evaluation of Surgery with Craniectomy for patients Undergoing Evacuation of Acute Subdural Haematoma) trial,¹⁸ a multicenter, pragmatic, parallel group randomized trial of DC versus CR for acute SDH, can help curtail this variation.

Brain edema significantly dictates the decision between DC and CR. Based on the variation in surgical decisions, the judgment regarding brain edema appears subjective. Our study sought to evaluate the influence of objective clinical and imaging factors on perioperative brain edema. We proposed that assessment of brain volume after traumatic brain injury (TBI) in patients without bone flaps is a reasonable model to study brain edema. In the study by Rossi-Mossuti et al.¹⁹ of 353 patients, 256 had surgical decompression of cerebrum or removal of focal hematoma, where significant intraoperative brain swelling was

documented in 50.6% of the procedures. Although this observation is subjective, this is congruent with our data, in which 61% exhibited positive $\Delta\%$.

The univariate analysis noted that the presence of IVH, initial GCS, preoperative MLS, and presence of contralateral injury significantly correlated with perioperative brain edema. The regression model found that both greater initial GCS and larger preoperative MLS were significant independent predictors for less brain edema; IVH contributed to a significant model, but its coefficient did not reach significance. Correlation between greater initial GCS and less brain edema agrees with the previous literature, because greater GCS is associated with less severe TBI and better clinical outcomes.²⁰⁻²² Moreover, the finding regarding contralateral injury is conceivable, as contralateral extra-axial findings should cause more brain edema. In addition, the finding regarding IVH is plausible. The presence of IVH have been associated with negative prognosis in aneurysmal subarachnoid hemorrhage^{23,24} and TBI.²⁵ Moreover, the extent of IVH also may influence cerebrospinal fluid dynamics, causing acute hydrocephalus that requires external ventricular drainage.²⁶ Wang et al.¹² noted that more ventricular deformation were associated with the decision to remove the bone flap.

Age, sex, laterality, presence of contusions, preoperative brain volume, preoperative SDH volume, area of bone flap, blood loss, sodium level, and hematocrit did not have significant relationships with $\Delta\%$. For acute SDH, though older age has been historically implicated as a poor clinical factor, a multivariate analysis in patient operated for acute SDH did not identify age as an independent predictor of outcome.²⁰ Sex has not been a significant factor associated with the decision between DC and CR^{1,14} but has been linked to adverse perioperative events.³ Laterality, sensibly, is not expected to influence brain edema. Surprisingly, contusions and preoperative SDH volume did not show significance; conceivably, these factors could influence $\Delta\%$ as both reflect the extent of brain injury; this may be related to low sample size in our cohort; however, the extent of brain injury, which includes contusion and SDH volume, also is reflected in GCS, IVH, MLS, and contralateral injury. Sodium level is the focus of hypertonic therapy and plays a role in brain edema; in our cohort, the perioperative values still varied within normal values, so the role of sodium may be marginalized.

We found that larger MLS was associated with negative $\Delta\%$ perioperatively. This finding conflicts with the prevalent idea that larger MLS equates to more severe TBI. Wang et al.¹² noted that larger MLS was associated with removed bone flaps. Our finding suggests that for larger MLS, the brain may be too deformed; consequently, despite SDH evacuation and removal of bone flap, the brain may not re-expand to its baseline volume immediately after surgery. This can be observed for treatment of chronic SDH, where pneumocephalus frequently fills the surgical cavity on the immediate postoperative scan, and the brain fails to promptly reexpand. The observations touch on the physics concept of elasticity, where a threshold could exist such that brain deformation becomes more resistant to re-expansion/swelling. Moreover, under significant compression, cerebrospinal fluid volume also gets depleted/redistributed, and some time may be required before this portion of intracranial volume returns. The finding that greater GCS scores and larger MLS both contribute to less brain

Table 2. Multiple Linear Regression Model

Model	Unstandardized Coefficients		Standardized Coefficients		95.0% Confidence Interval for B	
	B	Standard Error	Beta	P Value	Lower Bound	Upper Bound
(Constant)	16.197	2.435		<0.01	11.247	21.146
GCS score	−1.246	0.234	−0.591	<0.01	−1.721	−0.77
IVH	3.292	1.851	0.192	0.084	−0.471	7.054
Preoperative MLS	−0.986	0.183	−0.599	<0.01	−1.358	−0.614

GCS, Glasgow Coma Scale; IVH, intraventricular hemorrhage; MLS, midline shift.

edema may appear counter-intuitive, as patients with greater GCS scores tend to have smaller MLS and vice versa. That may not be the case for all patients, however, because those with good brain compliance may have a high GCS score despite a large MLS. Moreover, the regression model accounted for both variables.

This study had several limitations. First, analysis was limited to available CT imaging, which only included the immediate preoperative and immediate postoperative scans. Because brain edema does not peak until day 3–7 after injury, the findings missed the critical time period. Second, the analysis could not factor the compliance of the overlying skin above the cranial defect, which influences the measurement of the brain volume. Because surgical decision-making can be subjective and inconsistent, however, the findings can still guide prompt assessment

of preoperative/intraoperative/postoperative brain edema. Future studies that include scans at later time periods can further assess extent of brain edema.

CONCLUSIONS

A high proportion can exhibit negative $\Delta\%$, or relative brain compression, after decompression of SDH. For these patients, replacement of the bone flap may be reasonable to avoid obligatory interval cranioplasty. Preoperative MLS, initial GCS, and presence of IVH can help predict whether overall brain volume will swell or compress within the normal confines of the skull. This can guide the decision to retain or remove the bone flap.

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Received 7 June 2016; accepted 19 July 2016

Citation: *World Neurosurg*. (2016) 95:85-90.

<http://dx.doi.org/10.1016/j.wneu.2016.07.067>

Journal homepage: www.WORLDNEUROSURGERY.org

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